Global Strategy for the Conservation and Use of *Musa* (Banana) Genetic Resources

A consultative document prepared by the Global *Musa* Genetic Resources Network (MusaNet)

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CHAPTER 11.
EVALUATION OF *MUSA* GERMPLASM

SECTION 11.1 EVALUATION - WHERE WE ARE NOW

11.1.1 Introduction

According to the FAO 2nd State of the World Report on PGRFA (FAO 2010), one of the most significant constraints to the use of plant genetic resources is the lack of publicly available evaluation data for most accessions -even on standard agronomic and physiological traits- and the capacity to manage such data. Breeders and other researchers require readily available and comprehensive datasets to select germplasm for further studies, for use in breeding programs or for testing and promotion to farmers and other end-users. Data on agronomic traits, host reaction to pests and diseases and abiotic constraints, post-harvest characteristics and quality (and an integration of the available knowledge) are crucial to help scientists and potential end-users select the right materials.

There are different stages and levels of germplasm evaluation, including:

1. *In situ* assessment of genetic resources and compilation of indigenous traditional knowledge, to guide early selection and acquisition of new accessions with relevant traits into collections

1. Preliminary evaluation of accessions in *ex situ* collections, recording relevant observations on basic traits, such as general performance in the specific environment or fruit quality

2. Targeted screening of a wide range of germplasm for specific traits of interest through phenotyping and genotyping, including high-throughput mass-screening under controlled conditions

3. Evaluation in early stages of selection and preliminary yield trials to assess the performance of accessions for specific traits under field conditions

4. Advanced yield trials in multiple locations to fully assess the influence of the environment and growing conditions on the performance of promising accessions

5. Farmers' participatory trials in target end-user environments to select end-user-preferred accessions for cultivar release and wide-scale adoption.

These stages are not always clearly delineated, nor do they always take place in a linear (sequential) way.

11.1.2 Current status of *Musa* germplasm evaluation

It is estimated that there could be as many as 1,000 different banana cultivars (INIBAP 2006) and possibly up to 70 wild species (Häkkinen and Väre 2008). According to the MusaNet survey of *Musa* collections, 56 institutes conserve over 15,000 accessions (see Table D.2 - *Institutes managing* Musa *genetic diversity* in Annex D) that are thus potentially available for use by breeders, researchers, farmers or consumers. Below, we attempt to give an assessment of past and current evaluation activities of this banana diversity, and the main lessons learnt.

11.1.1.1 In situ *characterization and documentation of indigenous traditional knowledge*

Besides information on the taxonomic status of collected genetic resources and general information on the collection site, the Descriptors for Banana (*Musa* spp) (IPGRI-INIBAP, CIRAD 1996) also recommends collecting information on the use of the fruit and other plant parts, and on environmental conditions at the collection site. These can give a first indication of the value of the material and its host reaction to the prevailing biotic and/or abiotic constraints. The local name(s) given to banana genetic resources also often reveal useful information about the characteristics of the material. In addition, the so-called collector's notes, which capture relevant observations by the collector or local knowledge on traits of interest, are particularly informative and show that there is a wealth of knowledge to be captured at the time of collection.

11.1.1.2 Evaluation activities carried out by Musa ex situ *collections*

In the Global *Musa* Survey, between 48 and 50 collections provided information on the characterization, evaluation and breeding activities carried out with the germplasm from their collections.

Table 11.1. *Characterization, Evaluation and Breeding activities carried out by* ex situ *collections.*

Activity	Carried out on a routine basis	Carried out occasionally	Not carried out
Characterization for taxonomic traits (flower, fruits, etc.)	58%	38%	4%
Characterization using molecular markers	14%	36%	50%
Evaluation of host reaction to pests and diseases	35%	44%	21%
Evaluation of other important traits	50%	38%	12%
Breeding (hybrid or clonal trials)	26%	23%	51%

Half (50%) of the collections regularly carry out evaluation of other important traits, in addition to host reaction to pests and diseases (35%), and a quarter (26%) carry out hybrid or clonal trials on a routine basis. See Table 11.1 above for detailed results.

It thus seems that a significant number of accessions in collections are still not evaluated. In addition, for those accessions that have been evaluated, it is often hard to get access to the data. For example, only about one fourth of the 3,630 accessions recorded in MGIS have evaluation data, and only for a limited set of agronomic traits. These data most likely underestimate the real percentage of accessions evaluated and many more data for a range of traits may exist that are not necessarily available through MGIS.

11.1.1.3 Screening for agronomic performance and resistance to biotic and abiotic stresses

A quick review of publications in Musalit (www.musalit.org) dealing with germplasm evaluation indicate that most of these report on agronomic performance or host reaction to pests and diseases. Data on response to abiotic constraints and fruit quality traits appear to be less available. This is not surprising given that the principal traits sought by plant breeders are related to yield and its components (FAO 2010), and pest and disease resistance. We see the same trend in banana, with formal cultivar selection and crop improvement programs mostly focusing on a limited number of economically important traits, such as yield or disease resistance.

Despite this focus, there are still a number of important diseases for which no or very few natural sources of resistance have been identified. For instance, alarmingly few sources of resistance have been identified to Fusarium wilt tropical race 4 (TR4), which is already a major constraint to banana production in Asia and is spreading to other parts of the world. TR4 could potentially affect the lives of hundreds of millions of people dependent on bananas if no resistant cultivars with good consumer acceptance and market potential are available and adopted.

Drought is another serious constraint to banana production, for which there is little knowledge about tolerant cultivars. Some progress has been made in recent years to investigate the mechanisms underpinning drought tolerance, but more systematic, reliable field studies to screen the genepool for tolerance to drought is needed. With drought incidence expected to worsen in the near future, there is an urgent need to identify cultivars that are appropriate for drought-prone areas.

11.1.1.4 The International Musa *Testing Programme (IMTP)*

The International *Musa* Testing Programme (IMTP - http://www.promusa.org/IMTP) was established in 1989 by INIBAP in response to the needs of national programmes to provide famers with banana cultivars resistant to the major diseases affecting production. It was set up as a collaborative effort coordinated by Bioversity International to evaluate elite banana cultivars in multiple sites worldwide, using agreed evaluation protocols (Carlier et al. 2002; 2003).

There have been three phases of IMTP (starting in 1989, 1996 and 2005). In phase I, seven tetraploid hybrids developed by the banana breeding programme of FHIA in Honduras were tested for resistance to black leaf streak in six countries. Four years later, the recommendation was made to release three clones for distribution (Jones and Tézenas du Montcel 1994): FHIA-01 and FHIA-02, both dessert banana cultivars with outstanding agronomic performance and high resistance to black leaf streak, and FHIA-03, a cooking banana that also performed well. These three clones have since been distributed to more than 50 countries worldwide. In phase II, four programmes (FHIA in Honduras; EMBRAPA in Brazil; the Instituto de Investigaciones en Viandas Tropicales (INIVIT) in Cuba; and the Taiwan Banana Research Institute (TBRI) in Taiwan contributed germplasm, and the number of testing sites increased from 6 to 37. The results (Orjeda 2000) suggested that, among the different materials tested, FHIA-23 and SH-3436-9 were the most tolerant to black leaf streak. The improved hybrid with the best overall performance was FHIA-23. An improved cultivar that deserves special mention is GCTCV-119, which had the lowest discoloration score for both *Foc* races and good yields under good management.

Eighteen countries participated in phase III to which five breeding programmes contributed germplasm (FHIA in Honduras; IITA in Uganda and Nigeria; TBRI in Taiwan; CARBAP in Cameroon; and the CIRAD in Guadeloupe). For the first time, some partners carried out in-depth studies that involved epidemiological and ecological research, while the others undertook simplified performance trials against specific diseases. A standard procedure for data management and statistical analysis was also developed. ‘FHIA-25’, an AABB cooking type, had the highest average annual yield, followed by ‘FHIA-17’, an AAAA Gros Michel type dessert banana (Crichton and Van den Bergh 2016).

The IMTP allowed for new materials coming out of breeding and selection programmes to be evaluated in a range of environments and to become more widely known to next users. The IMTP also stimulated further local testing of a subset of new materials with beneficial traits for the specific country or location. The materials included in the different phases of the IMTP have all been shared with the ITC and are available for distribution to interested parties. Trial sites, mainly geared to assessing resistance to Fusarium wilt, black leaf streak and later also nematodes, were increasingly also used for other evaluations (e.g. fruit micronutrient content) or to answer key questions about pathogen, disease and host interactions. The IMTP also sought to strengthen the capacity of national institutes to evaluate improved materials and to carry out research on banana for local consumption.

11.1.1.5 Participatory varietal selection

Adoption and impact on local communities of new banana cultivars has often been slow and lower than expected. This may be at least partly explained by the fact that evaluation programs often focus on a few economically important traits and that farmers are mostly involved only at the very end of the testing pipeline. This approach fails to take into account other potentially important traits for which the economic value may be more difficult to assess, such as traits related to consumers’ taste preferences, local recipes, cultural values, or the relative role of men and women in production, processing and marketing. Working in close collaboration with farmers during the whole evaluation process allows the quantification of the suitability of each cultivar to local farming conditions, while sensory evaluations with consumers provide feedback on taste and other organoleptic features, as well as processing potential.

While having shown its value in the evaluation and adoption of other crops, such as rice and potato, true participatory varietal selection is still relatively unexplored in banana. Only a handful of publications in Musalit specifically mention a participatory evaluation approach in their title, though it is believed that more participatory trials are actually being conducted.

SECTION 11.2 EVALUATION - WHERE WE WANT TO GO

11.2.1 Banana types and uses around the world

For cultivars to be used and adopted, they need to respond to the real needs and preferences of the target end-users, and this needs to be taken into account throughout the evaluation process. As highlighted above, evaluation programs often focus on a limited number of economically important traits, thus failing to take into account other potentially important traits for which the economic value may be more difficult to assess, such as traits related to consumers preferences (taste, flavour, processing ability, satiety feeling), cultural values, or the relative role of men and women in production, processing and marketing.

Banana cultivars, and the traits they are selected for, differ significantly between regions, and between locations within regions. Globally, different types of cultivars are grown for a variety of uses, and pest and disease constraints have different importance depending on the region, as environmental conditions are often complex and highly variable.

In Asia and the Pacific, the most important banana group is the Cavendish (AAA) type accounting for 59% of regional production, either for export (China, Taiwan, India, and Philippines) or for local use (Indonesia, Philippines, Vietnam, Cambodia, Australia and Thailand). Gros Michel (AAA) and other dessert bananas make up a further 16% of production (Philippines, Indonesia, India and Malaysia). The remaining 25% of production are cooking bananas, that are of medium to high importance in some countries, comprising AAB ‘Maoli-Popo’ulu and Iholena’, ABB Pisang Awak, Bluggoe, and Saba.

In West and Central Africa, plantains (AAB) are of major importance and account for 69% of the production, mainly for local consumption. Dessert banana (e.g. Cavendish, Gros Michel) are of medium importance (24% of production), both for export and local markets. In East and Southern Africa, highland bananas (AAA) and other cooking types (ABB) make up 76% of the total production and are of major importance for different uses. Plantains are of lower significance (7% of production) than in West and Central Africa and dessert types account for 17% of production in the region.

The bulk of production in Latin America and the Caribbean is of the Cavendish type, followed by plantains, other dessert types and other cooking types. The region is a major exporter of banana, accounting for 66% of global Cavendish exports, and also produces 72% of plantains traded on international markets. Nevertheless, 62% of banana production in the region is consumed locally, which indicates the high importance of the crop in local diets and food security throughout the region. Important cultivar groups for local consumption are Prata (AAB) in Brazil, Silk (AAB) in all Latin American countries, Gros Michel (AAA) in Central and South America in intercropping with forest trees, coffee and cacao, Bluggoe and Pisang Awak (ABB) in Nicaragua, Mexico and Cuba, and finally the important group of the Plantains (AAB).

If adoption of cultivars by end-users is the final goal, the trait preferences of the different stakeholders along the value chain -including producers, processors, traders, consumers- need to be taken into account throughout the evaluation process.

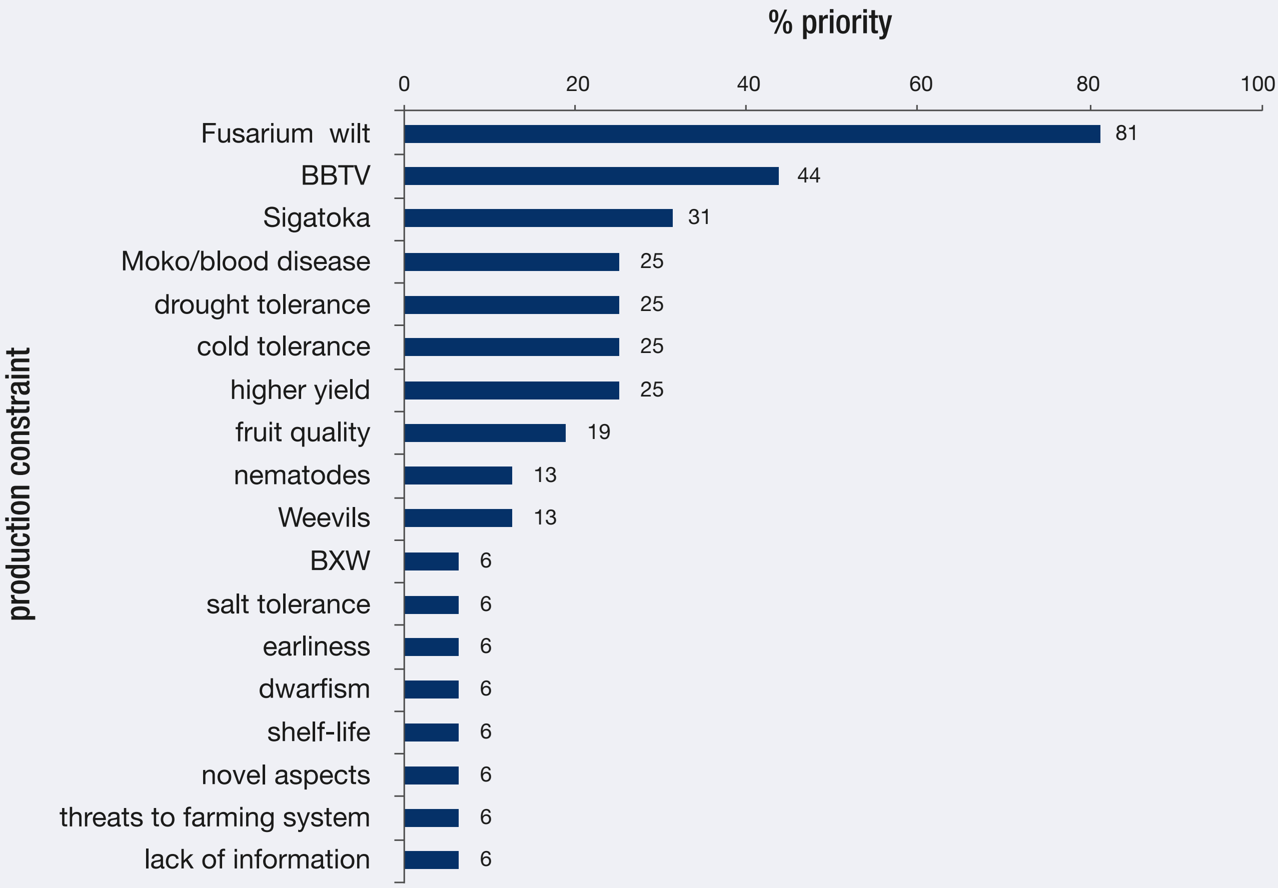
11.2.2 Traits to be evaluated

11.2.2.1 Global scale

At the MusaNet meeting in March 2011, the following traits were identified by the Evaluation Thematic Group (ETG) as being of global importance: resistance to Fusarium wilt, banana bunchy top and black leaf streak, drought tolerance, shelf life, dry matter content, vitamins and minerals content, height, yield and finger drop resistance.

In 2012, participants to the MusaNet/Trust meeting in Bogor, Indonesia confirmed the importance of the three major diseases previously identified, namely Fusarium wilt, BBTV and black leaf streak, and the main abiotic constraints, namely drought (Figure 11.1 below).

Figure 11.1. *Priorities assigned to the major production constraints by the participants of the MusaNet/Trust Bogor meeting in 2012.*



They also discussed the expected impact of climate change on *Musa* breeding objectives, and the need to evaluate more materials for more traits that could be of economic importance in the future. It was suggested that breeding programmes should focus efforts on the following traits in preparation for climate change: wind tolerance (shorter plants and strong root system for a better anchorage), drought tolerance (also including shorter cycles/early fruiting to avoid dry periods), salt tolerance, and plasticity regarding variation in rainfalls and succession of drought/flooding.

The 2013 RTB online research priority setting survey[1] of *Musa* experts eliciting the most important constraints to banana yields and farmers' income also saw that main production constraints varied significantly from region to region (see Table 11.2), but in all regions, and across the CGIAR, banana pests and diseases ranked highest, although there was little significant difference between most of these. They also varied according to cultivar group. In terms of diseases, black leaf streak[2] (BLS, or black Sigatoka) *Mycosphaerella fijiensis* ranked the most serious constraint, followed by Fusarium wilt[3] caused by the soil-borne fungus *Fusarium oxysporum* f. sp. cubense (Foc), then banana bunchy top virus[4] (BBTV), and banana *Xanthomonas* (bacterial) wilt[5] (BXW). The two pests, banana weevil[6] (*Cosmopolites sordidus* (Germar)) and burrowing nematode[7] (*Radopholus similis*) are considered slightly more threatening than BXW or BBTV.

11.2.2.2 Regional scale

Other traits are more of regional importance. Meetings held by the four banana networks (BAPNET, BARNESA, MUSALAC, Innovate Plantain[8]) are critical in identifying regional priorities. The networks are represented in MusaNet and thus contribute to MusaNet's objectives and activities. See Annex A on networks and partnerships for more information.

The most recent BAPNET consultation (2014) brought to the fore the need for the collection of new varieties and evaluation of accessions already held in regional genebanks for traits such as drought tolerance and disease resistance. Another priority is establishing a framework for investigating what diversity is being used in the region so that breeders as well as farmers can easily access what is already available.

MUSALAC, which meets every couple of years, has recently focused on Fusarium wilt tolerance, soil health and suppressiveness and climate change and adaptation. Screening Asian cultivars for TR4 tolerance is a current concern. They also proposed that information resulting from evaluation trials needs to be made available to the public through a searchable database in order to facilitate priority setting.

BARNESA priorities have included investigation into disease resistance, particularly Banana *Xanthomonas* wilt (BXW) and work on *in situ* and on farm conservation practices.

Innovate Plantain priority activities have focused on better management of pests and diseases, access to clean planting material and discovery and use of traits to mitigate the effects of climatic change.

During the initial MusaNet meeting and subsequent follow-up interactions, the ETG identified, for different types of bananas in different regions, the major traits that need evaluation (see Table 11.2).

Table 11.2. *Important traits for different banana types in different regions.*

1 http://www.promusa.org/tiki-read_article.php?articleId=92

2 http://www.promusa.org/Black+leaf+streak

3 http://www.promusa.org/Fusarium+wilt

4 http://www.promusa.org/Bunchy+top

5 http://www.promusa.org/Xanthomonas+wilt

6 http://entnemdept.ufl.edu/creatures/fruit/borers/banana_root_borer.htm

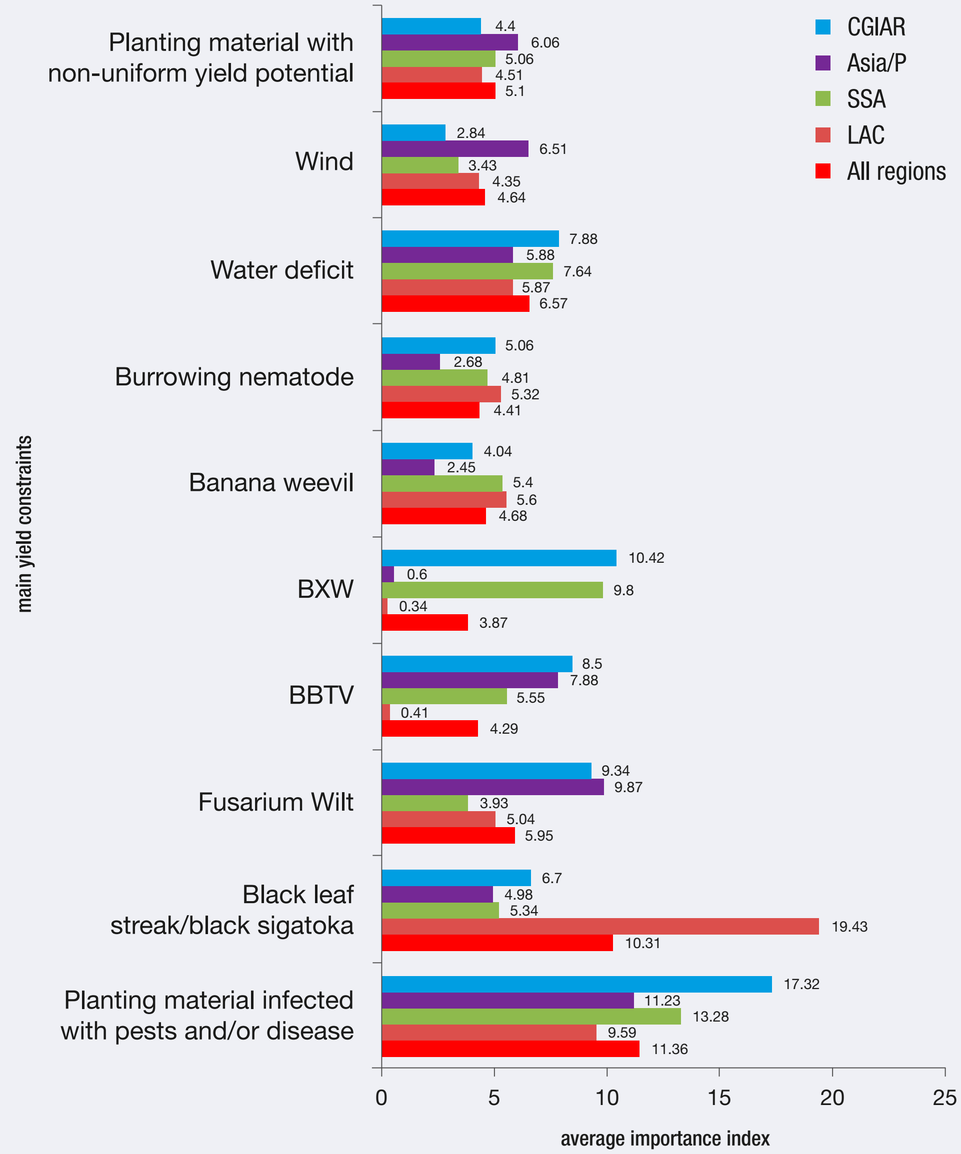
7 http://www.promusa.org/Radopholus+similis

8 http://banana-networks.org/

Banana Types	Asia-Pacific	West and Central Africa	South East Asia	Latin America and Caribbean
Cavendish export	Fusarium, nematodes	Yield, ratio bunch/box, plant height, crop cycle, BLS, YS, Fusarium R1, Tropical Race 4 (TR4), nematodes, weevils, finger drop, fruit taste, fruit green life, fruit tolerance to cold in post-harvest chain, peel thickness, peel splitting		Yield, ratio bunch/box, plant height, crop cycle, BLS, YS, Fusarium R1, TR4, nematodes, weevils, finger drop, fruit taste, fruit green life, fruit tolerance to cold in post-harvest chain, peel thickness, peel splitting
Cavendish local use	Fusarium TR4, BBTV, BLS, nematodes, drought, wind (typhoons)			
Gros Michel and other dessert	Fusarium R1, TR4, BBTV, BLS, nematodes, drought, wind (typhoons)		Bacterial wilt, Fusarium, BBTV	
Maoli-Popo'ulu and Iholena plantains	BLS, BBTV, nematodes, drought, wind (typhoons), vitamin A content	Nematodes, weevils, drought, Fusarium, BBTV, BLS, cooking quality (starch/fibre), nutritional compounds, finger drop, green/shelf life	Weevils, root system, BBTV	Cooking ability (starch), green/shelf life, fruit taste, nutritional compounds
East African Highland Bananas			Weevils, bacterial wilt, nematodes, drought, BBTV, BLS, Fusarium, Green/shelf life	Cooking ability (starch), fruit taste
ABB cooking bananas	Bacterial diseases			Cooking ability (starch), soluble solids

The 2013 RTB online research priority setting survey also saw that main production constraints varied significantly from region to region (see Figure 11.2 below). They also varied according to cultivar group. BLS is hugely important in Latin America); while Fusarium wilt is more important in the Asia Pacific region (although the virulent tropical TR4 has now also entered Africa). BBTV is much less important in Latin America than elsewhere, and BXW is much more important in Africa than the other two regions. The two pests, Banana Weevil (*Cosmopolites sordidus* (Germar)) and burrowing nematode (*Radopholus similis*) are more or less equally important in the different regions.

Figure 11.2. *Main production constraints per region, as identified by the 2013 RTB online research priority setting survey.*



One recent iniative that will contribute to a better understanding of regional diversity is the inventory of the top 10 *Musa* varieties in each country. This is being carried out in several regions: in Latin America and Caribbean, collections are being surveyed in 2016 about their usage of ITC material and their most successful cultivars, while in West and Central Africa, a discussion on the top varieties took place at the regional MusaNet workshop in Cameroon in 2015. One of MusaNet's objectives is to expand this inventory to all regions and make the results available to collection curators and breeders, so that they can select and test varieties that have been successful in other countries/regions.

11.2.2.3 Local scale

However, for effective adoption to take place, evaluation programs will also need to take into account end-user preferences at a much more local scale. Breeders and other researchers require information on end-user needs and preferences, and need to link these to traits that can be objectively measured.

SECTION 11.3 – EVALUATION - HOW WE WILL GET THERE

11.3.1 MusaNet Evaluation Thematic Group (ETG)

The overall goal of the MusaNet ETG is to enhance the value of *Musa* genetic resources for different end users (including farmers, curators, breeders, and researchers) and thus encourage their use to improve the sustainability of banana productions systems and farmers' livelihoods.

Musa genetic resources (including wild species, landraces, cultivar selections and improved materials) need to be evaluated for traits of interest, such as agronomic performance, host reaction to pests and diseases and post-harvest characteristics, under diverse environmental conditions through a user-oriented network. This process is expected to result in a better understanding of the *Musa* genepool and of the interactions between *Musa*, its major pathogens and the environment, and will eventually lead to an increased efficiency of banana breeding programmes and the development of more robust farmer recommendations. The resulting information and knowledge needs to be compiled and made available, and important traits highlighted to potential users.

As part of a global network, the ETG will focus on traits of global relevance where cross-regional collaboration and learning is important and on traits of special importance in regions where high food insecurity and poverty incidence coincides with high importance of banana for food security or income generation. To still capture locally important traits, gender-sensitive participatory rural appraisal tools can be used to document the needs and preferences of the different actors along the banana production and value chains, to achieve a better understanding of underlying factors that determine the value that farmers and consumers attribute to different traits, and the criteria that they use for adoption or rejection of cultivars. Special attention should be given to the different roles, needs and preferences of men and women.

The three main user groups identified are: breeders, the research community and farmers. The members of the ETG will have to work in close collaboration with researchers from different disciplines (agronomy, plant pathology, post-harvest, crop physiology, etc.), members from the other MusaNet Thematic Groups, curators of collections and many others.

The four regional networks need to play an essential role in terms of regional coordination of activities, and ensuring the link with the end-users (farmers and consumers). They should continue to share their priorities with the ETG for future planning of activities within MusaNet. There also needs to be close collaboration with the ProMusa community, especially in the area of knowledge management.

In order to allow comparison of evaluation data for specific traits between different environments and over time, there is need to develop and agree on a set of standard "best-practice" protocols for priority traits, as well as a standard set of reference cultivars. The ETG can play a role in the development of such guidelines.

11.3.2 Global evaluation platform

Despite the positive results of the previous phases of the program, the IMTP has also received some critical feedback, with the most important one probably being the fact that the adoption of the new cultivars has in general remained low. In addition, a real analysis of the interaction between the performance of the different genotypes and the environment (GxE analysis) was often not possible. Also, the trials were expensive, and most trials were carried out at the partner's own expense.

Therefore, the format of future trials is changing to maximize chances for adoption of the new cultivars. Trial groups will be organized around certain banana types and targeted to relevant end-user environments. A variety of participatory rural appraisal tools will be used to identify, prioritize and document the needs and preferences of the different actors along the banana production and value chain.

Two types of trials will be run consecutively: on-station trials to gain accurate data on cultivar performance, and on-farm participatory selection trials to facilitate access to and testing of the new material by end users (known as 'mother-baby' trials). The experimental design of the on-station trials has been optimized to include better characterization of the abiotic environment, simplification of the variables to be measured, and the grouping of variables into core and additional modules. Farmers are being invited to visit the on-station trials and select a subset of cultivars for testing in their own fields. The on-farm trials are fully managed by the farmers, who will rate the performance of the new cultivars in comparison with their local checks. Through farmers' group discussions, household-level surveys and stakeholders' interviews, and linking socio-cultural traits and taste preferences with morphological and physicochemical fruit properties, a better understanding will be achieved of underlying factors that determine how farmers and consumers make choices, the value they attribute to different traits in their local context, and the criteria they use for adoption or rejection of cultivars. Special attention will be given to the different roles, needs and preferences of men and women.

It is hoped that the new format will enable a more efficient mechanism for the evaluation of banana cultivars, and lead to faster adoption and greater impact on the lives of banana-dependent populations.

11.3.3 Strategic plan

The MusaNet ETG will help coordinate banana evaluation activities globally, by bringing together experts in the field, reviewing currently available information, standardizing evaluation protocols to allow comparison of performance between locations and over time, establishing a framework for data compilation and analysis, and communicating the results and available knowledge to relevant end-users.

More details on each of these activities are given in Table 11.3 below.

Table 11.3. *Proposed objectives and actions for* Musa *evaluation.*

Specific objectives	Actions
1. Comprehensive assessment of currently available evaluation data	• Review of literature on evaluation of *Musa* genetic resources • Review of currently available phenotypic and genotypic evaluation data information in MGIS and other collection databases • Identify major gaps in knowledge in terms of traits and accessions
2. Standardization of evaluation protocols	• Review currently available phenotyping/genotyping methodologies for evaluation of priority traits • Identify gaps in evaluation methodologies; identify for which traits and/or types of evaluation good protocols are not available • Develop and agree on a set of standard "best-practice" protocols for priority traits, and enter standardized traits/methods in Trait Ontology • Agree on a set of standard check genotypes for all trials • Identify a set of well characterized (climate, soil conditions, etc.) reference trial sites
3. Set up framework for data compilation and analysis	• Compile existing evaluation data in *The Global Agricultural Trial Repository of CCAFS* (AgTrials) (www.agtrials.org) • Ensure link between AgTrials and MGIS • Ensure link between AgTrials and Trait Ontology • Engage in global analyses for germplasm performance and GxE interactions
4. Information and knowledge sharing	• Make available and pro-actively share information and knowledge with the broader *Musa* research community and other users/stakeholders, in collaboration with MusaNet's Information Thematic Group and the global network ProMusa (www.promusa.org) • Make available a database search tool for information on different varieties that are being screened, such as agronomic, climatic and quality characteristics, in order to help priority setting in the regions.